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National Wood In
Transportation Information
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Morgantown, WV

NA-TP-02-96

The Identification of Market Opportunities for Wood in the United States Transportation System

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The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1994

PREFACE

This publication is a technology transfer effort by the USDA Forest Service, National Wood In Transportation Information Center, in cooperation with the Center for Forest Products Marketing, Department of Wood Science and Forest Products at Virginia Polytechnic Institute and State University under a grant from the USDA Forest Service.

This publication examines current consumers of wood products in the United States' four transportation systems: the highway system, the railroad system, the marine and waterway system, and the electricity and communications transportation system. The study investigates how these consumers chose their infrastructure materials, and it determines if there are ways to influence their decisions on the materials they utilize.

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The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1994

The Identification of Market Opportunities for Wood in the United States Transportation System

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August 1997

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INTRODUCTION

The United States highway system consists of 3.9 million miles of roads and streets, with 3.1 million of these miles located in rural areas. There are approximately 577,000 bridges in the highway system, with 270,000 of these on the federal-aid system. The main consumers of wood products in the highway transportation system are local, state, and federal governments. The ownership breakdown for highway systems is:

- local government — 75 percent,
- state government — 20 percent, and
- federal government — 5 percent.

Highway construction and maintenance is financed in a variety of ways, including direct user fees, license fees, tolls, taxes, and local property assessments. The transportation infrastructures in this study include the road and highway system, the marine and inland waterway transport system, the railroad system, and the electricity and communications transport system within the United States.

The 1990 census estimated that the 1988 funding collected by all governments for highway use amounted to $69 billion. The percentage breakdown for fund collection was:

- federal government — 48.1 percent,
- state government — 49.7 percent, and
- local government — 2.2 percent.

The distribution of funds was:

- capital improvements — 48.1 percent,
- maintenance — 22.7 percent, and
- all others — 29.2 percent.

The areas of main concern to the wood products industry include capital improvements and highway maintenance. The wood products purchased as highway capital improvements and highway maintenance expenditures are guardrails, sound barriers, bridge materials, sign posts, salt storage buildings, and formwork and falsework. Due to the large expenditures on highway maintenance and improvements each year, market knowledge for wood products in highway transport is beneficial to the wood products industry (National Transportation Strategic Planning Study 1991).

The second market for wood products in transportation is the railroad system. Railroads in the United States are predominantly owned by individual companies that have exclusive rights to the tracks and facilities. The railroad was at one time the leading transportation method in the United States, but several factors have caused the railroad's role in transportation to become less dominant. First, the construction of an efficient highway system and affordable air travel have greatly reduced rail freight and passenger service. Rail passenger travel has been reduced to less than 5 percent of total passenger-miles traveled, and the share of United States freight transported by rail has dropped from 60 percent in 1940 to 35 percent in the 1980s. Second, economic activity has been dispersed away from urban areas to suburban and rural areas, indicating less dependence on strong rail transport concentration centers. Third, the economy has shifted from heavy industry to specialized manufacturing and services that require smaller shipments and more flexible transportation (National Transportation Strategic Planning Study 1991).

The total transport of freight reported by United States railroads in 1990 was over 1 trillion ton-miles and more than 1.6 billion tons of freight. The tremendous amount of freight moved each year puts stress on the track system, and the yearly expenditures on track are a major market for the wood products industry. The main wood products used by the railroad are crossties and switch ties. There is little public knowledge concerning the physical condition of the United States freight rail system because it is mainly held by the private sector. New crosstie installation has declined in the past few years, but class I railroads continue to spend significant amounts on maintenance of way, structures, and on capital expenditures for railroad way and structures.[1] Maintenance of way and structure expenditures include keeping the railroad tracks free of vegetation and debris as well as maintaining the tracks. Maintaining the tracks is done by adding ballast, replacing decayed and broken crossties, and monitoring bridges, road crossings, and railroad signals. Class I railroads annually spend $4.4 billion on maintenance of way and structures and $2.7 billion on capital expenditures for railroad way and structures. The smaller class II and class III railroads are expected to spend over 11 billion dollars from 1990 to 2020, with more than 25 percent of this expected to be spent on rail rehabilitation, including tie replacement (National Transportation Strategic Planning Study 1991).

The maintenance of way activity by the class I railroads has slowed considerably since the major track and crosstie replacement of the 1970s, with several factors influencing this trend. First, the system is in good condition and does not require material replacement. Second, redundant and uneconomical lines are being divested by class I railroads, leaving fewer miles of track to maintain. Third, new material technology is prolonging the service life of many track components. The smaller railroads experience less traffic and travel at slower speeds, so track maintenance requirements on them are not as great as class I railroads. Therefore, less is spent on crosstie replacements on smaller railroads than class I railroads. Finally, major rail maintenance work has historically occurred in waves, with the most recent work in the 1940s and the 1970s. It's predicted that the next substantial replacement cycle will occur in the next decade (National Transportation Strategic Planning Study 1991).

The third form of transportation addressed is the marine and inland waterway system. The waterborne transportation system consists of vessels, channels, piers, wharves, cargo handling equipment, storage facilities, and connections to other modes of transportation. These structures require tremendous amounts of wood products to build and maintain them. The storage facilities, piers, and wharves will require lumber, timbers, and pilings to be constructed and maintained. The channels, including locks and dams, will require lumber, timbers, and plywood panels for the formwork and falsework used in their construction.

The operators of marine and inland ports are from the public and private sectors. The public sector is operated by the U.S. Navy and the U.S. Army Corps of Engineers. The Army Corps of Engineers has the primary responsibility for keeping the United States waterways clear and navigable. The public sector represents a large market in both inland waterways and marine ports construction. The private sector of marine transportation is operated by individuals who own the ports and sub-ports or people who lease these marine facilities from the owners. These marine transportation systems and their owners and operators represent a large market for the wood products industry.

The last market addressed is the electricity and communications transport market. Utility poles are the main product of concern to the wood products industry. The consumers in this market are public electric utilities, investor-owned electric utilities, federal electric utilities, and cooperative borrowers.

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[1] The Interstate Commerce Commission classifies firms in the railroad industry into three classes:

1. Class I — railroad companies with an annual operating revenue of $50 million or greater;
2. Class II — companies with an annual operating revenue less than $30 million but greater than $10 million; and
3. Class III — compan ies with an annual operating revenue less than $10 million (McCurdy and Case 1989).

The telecommunications industry is another consumer of utility poles. Together, these two industries supply approximately 2.62 million citizens of the United States with power and telephone service, which is still largely transmitted and distributed over utility poles. These two industries use more than 2 million new poles each year at a cost of approximately $200 to $400 per pole, equating to a $600 million market annually (Ng 1994).

This project studies current consumers of wood products in these four United States transportation systems. This literature review gives product descriptions for each wood product, followed by the size of the market, and the current marketing practices. The competitive products are described, including their advantages and disadvantages compared to wood products. Finally, this review discusses new wood product designs and opportunities for wood products in each transportation area.

THE HIGHWAY SYSTEM

Besides bridge structures, there are four categories where wood products can be utilized in the highway system:

- guardrails,
- noise barriers,
- signs and sign posts, and
- formwork and falsework.

These will be discussed in the following pages.

Highway Guardrails Description

Guardrails are protective structures constructed parallel to roads and highways. Guardrails are primarily constructed of steel or wood posts driven into the ground at 10-to 15-foot centers. Railing is attached at the top, which is usually made of steel beams with W cross-sections or triple V cross-sections, wood timbers, or steel cable. Guardrails are frequently constructed to keep vehicles from traveling off elevated roadways or to keep vehicles from colliding with pedestrians or stationary objects, such as houses, poles, or trees. Guardrails are also used to separate multi-lane roads where median strips are impractical.

Wood Guardrail Markets

The market size for guardrails covers the entire United States road and highway system. Anywhere that a road hazard would warrant the use of a guardrail, i.e., a road along the edge of a hill or close to buildings, is an opportunity for the use of wood guardrails.

Wood guardrails may be considered a mandatory safety product. The Federal Highway Administration (FHwA) has implemented a road hazard elimination program to evaluate highway safety improvements, including highway guardrails. These improvements have been responsible for saving 50,000 lives and preventing 850,000 nonfatal injuries since 1974 (Office of Highway Safety, U.S. Department of Transportation 1993). Table 1 (page 4) shows the amount spent on highway guardrails (all material types) between 1974 and 1992.

Table 1. Cost of Upgrading Highway Guardrails, 1974 to 1992.

Construction Upgrade	Cost ($millions)	Percent Reduction in Accident Rates After Improvements			Benefit-Cost Ratio
		Fatal	*Nonfatal Injury*	*Combined Fatal and Nonfatal Injury*	
Bridge Rail	8.0	75%	29%	33%	7.1
Guardrail End Treatment	6.4	52%	15%	16%	3.0
Guardrail	178.3	37%	8%	9%	7.9

Source: Office of Highway Safety, U.S. Department of Transportation, "The 1993 Annual Report on Highway Safety Improvement Programs" F.H.W.A.-S A 93- 019, Washington DC.

Guardrail Markets

The highway engineer in charge of construction will specify the material type to be used, or the state government may have certain specifications for the type of guardrail system to be implemented. Highway engineers will specify materials according to past experiences and policies of the state government. Georgia officials banned wood posts (except for end posts) in guardrail systems because they received poorly treated wood posts. The poor quality product Georgia officials experienced is not expected to be a widespread trend. Some states that use wood posts in guardrail systems are Texas, Connecticut, Ohio, Kentucky, and West Virginia (Bowlby 1992).

Competition

Steel posts are the main competition for wood constructed guardrails. Guardrail post installation is a large expense in time and effort. Another concern is the damage that may occur to the posts below ground level. In a study performed by Gatchell and Lucas (1971), 32 wooden posts and 26 steel posts were driven into a rock-filled base soil that was topped with limestone gravel and shale. They found that both post materials performed well, but that wood was superior to steel in resisting damage below the ground surface. Punches (1993) study of wood versus steel guardrail posts demonstrated similar results as Gatchell and Lucas. These results can be seen in Table 2 (page 5). In soft soils, wooden posts may be preferred because of their large soil-bearing surface. In rocky soils, wooden posts may be selected because of their ability to resist damage. On certain types of granular fill and on soft shoulders, steel guardrail posts may be preferred. Because of the steel post's small surface area, soil disturbance is minimized. The type of guardrail post should be carefully specified depending on soil considerations.

Opportunities for Wood Products in Guardrails

Richard Bowlby (1992), of Burke, Parsons, and Bowlby, estimates the current cost per unit of guardrail system to be $20 for steel and $11 for wood. Punches (1993) says a possible market for wood in guardrails are the blocks connecting guard railing to the post. Currently, most states either use wood blocks on wood posts or steel blocks on steel posts. Wood blocks are cheaper than steel blocks, and installation difficulty and expense are the same. Current designs for wood block guardrails allow one hole for rail attachment. This will allow for faster railing installation, but can also permit the block to turn during construction. New block and post designs may prevent blocks from turning during construction (Punches 1993).

Table 2. Steel Posts Versus Wood Posts in Guardrails.

Advantages of Steel Posts:	**Advantages of Wood Posts:**
• Drive easier in all soils, especially in hard materials (asphalt, soil cement) • Drive faster • Weigh less • Handle easier • Bolt to guardrail easier • Damage to tight shoulder less likely • Can drive in rocky soil and will split or drive around rock, may split soft rock, and will drive through shale • Bend upon impact, rather than breaking; this allows a secure hold for removal	• Individual posts are less expensive • Do not become cemented in place • Have a better appearance • Drive well in loose fill or clay
Disadvantages of Steel Posts:	**Disadvantages of Wood Posts:**
• Are more expensive • May become cemented in soil and be difficult to remove	• Are not practical unless soil conditions are right for construction • Are difficult to install in straight line, so guardrail may not be straight • Have to drill rocky soil • may break off at ground level on vehicle imact, making replacement difficult • Are difficult to drive in granular soils • Haul less per load (300/load) • May damage a poorly compacted or tight shoulder • Decrease production of guardrails 25 to 30 percent

Source: Punches 1993

Highway Noise Barriers Description

Highway noise barriers are protective walls constructed parallel to roads and highways. These barriers reduce the level of noise to areas near the highway and break the line of sight between the vehicles on the highway and area residents. Noise barriers have two major designs: vertical walls and earth berms. Masonry, concrete, earth, metal, wood, vegetation, and combinations of materials have been used in barrier construction. There is no indication that any material dominates the market. The height range is 5 feet to over 20 feet tall, with length of these walls varying by the sound protection needs. The longer the span of residential or work places, the longer the noise barrier (Weiss 1988).

Noise Barrier Markets

The U.S. Environmental Protection Agency estimates that more than 90 million people in the United States are exposed to excessive highway noise levels. Naturally, these high exposure areas are excellent opportunities for wood noise barriers. By the end of 1980, more than 189 miles of noise barriers had been constructed in 31 states and Puerto Rico. Eighty-five percent of these barriers are in nine states: California, Minnesota, Colorado, Virginia, Oregon, Arizona, Washington, Massachusetts, and Connecticut (Cohn 1981). By the end of 1986, more than 450 miles of noise barriers had been built in the United States at a cost of more than $ 300 million (Weiss 1988).

In a study, Weiss (1988) states that future construction of noise barriers is expected to be tens of miles annually, with an average cost of $12 per linear foot for wood. This represents a market for wood products valued at $3.8 million annually (Weiss 1988). Table 3 contains the total length of each barrier type in place in the United States as of 1990.

As seen in Table 3, there are more noise barriers constructed from block/concrete and all concrete, than from wood. The total amount spent on different noise barrier types as of 1981 is found in Table 4. Note that wood noise barrier construction is also third in dollar amounts invested by states. The states that implement the noise barriers can be seen in Table 5 (page 7). California has the most noise barriers because of its high population, while Minnesota comes in second because of a noise barrier initiative program.

The principle decision makers for the noise barrier construction process are highway engineers in teams consisting of design engineers, planning engineers, and environmental engineers. Nearly three-fourths of the 27 states surveyed by Cohn (1981) in his study of highway noise barriers allow some form of community involvement in design issues. This is accomplished primarily through the public hearing process (Cohn 1981).

Table 3. Barriers Constructed in the United States.

Material Type	Total Length (mi)	Percent
Block/Concrete	148.1	32%
Concrete	91.2	20%
Wood	68.9	15%
Berm	47.4	10%
Metal	22.6	5%
Berm/concrete	18.0	4%
Berm/wood	9.8	2%
Berm/metal	6.7	1%
Other	54.2	11%
Total	***466.9***	***100%***

Source: "Cost of Noise Barrier Construction in the United States," by Louis F. Cohn and Roswell A. Harris. Transportation Research Record 1255: Energy and Environment 1990: transportation - induced noise and air pollution. Transportation Research Board: National Research Council, Washington DC 1990.

Table 4. Materials Used In Highway Noise Barriers, 1981.

Barrier Type	Length (ft.)	Cost in 1980 Dollars
Concrete	464,475	48,600,000
Combination	232,759	33,500,000
Wood	157,746	16,600,000
Earth Berm	128,711	5,900,000
Metal	142,298	2,000,000
Other	2,474	500,000
Total	***100,463***	***107,100,000***

Source: "Highway Noise Barriers," by Louis Cohn. National Cooperative Highway Research Program: Synthesis of Highway Practice 87. December 1981.

Table 5. Highway Noise Barrier Construction by State, 1986.

Construction by Length		**Construction by Cost**	
State	***Length (linear mi)***	***State***	***Cost (1986 $ millions)***
California	148.1	California	116.5
Minnesota	47.6	Minnesota	41.6
Colorado	31.2	Virginia	26.6
Virginia	26.1	New Jersey	21.5
Oregon	20.8	Michigan	16.3
Michigan	18.6	Tennessee	13.2
Arizona	17.1	New York	13.0
New York	17.1	Illinois	10.1
New Jersey	15.8	Pennsylvania	8.9
Washington	14.5	Oregon	8.7
10-State Total	***356.9***	***10-State Total***	***276.4***

Source: "Summary of Highway Noise Barrier Constructin in the United States," by Martin Weiss. Transportation Research Record 1176: Research on Noise and Environmental Issues. Transportation Research Board, National Research Council, Washington, DC 1988.

Criteria Used To Evaluate Noise Barriers

The principle criteria used to determine the height and length of highway noise barriers is the Federal Highway Administration's design noise level. Some states require the line of sight between the source and receiver of the noise be broken. Most states will not install a noise barrier unless it will result in a noise reduction of at least 10 decibels, although some states use 5 decibels as the noise reduction criterion (Cohn 1981). A decibel (dBa) is the unit for expressing the relative intensity of sounds on a scale from 0 decibels as the average least-perceptible sound, to 130 decibels, the average pain level (Webster 1994).

Cohn (1981) presents several criteria to consider when constructing a noise barrier. First, it should be aesthetically pleasing. The effectiveness of the barrier can be as greatly influenced by aesthetics and landscaping as by acoustical performance. Second, the community has to accept the barrier. Third, the cost should be optimized. As shown in Table 3 (page 6), wood is the third largest percentage of total noise barriers constructed by 1990. This may be because wood is fairly inexpensive, will last a long time, and can be aesthetically pleasing if constructed correctly. The last factor to consider is that a noise barrier must reduce noise to the desired level to be effective (Cohn 1981).

Wood Noise Barrier Problems

Wood noise barriers have had several problems, mainly pertaining to design and aesthetics when not constructed correctly. Cohn (1981) states the first problem with wood barriers is the lack of uniformity in the barrier color. Second, Cohn points to problems with wood shrinkage and warping. Shrinkage and warping of wood causes cracks in the barrier, thus decreasing effective noise reduction.

In a report on the problems with performance of wood noise barriers, Sterling states that some of the wood noise barriers in Virginia began to warp and crack within a short time after installation. The main causes for shrinkage and swelling in wood barriers are attributed to moisture content. These noise

barriers were expected to require little maintenance; however, substantial repairs were needed after only a few years. The construction specifications allowed 19 percent moisture content, and since that time it has been determined that moisture content in excess of 15 percent will cause warping. The second cause of the warping and shrinkage has to do with the size of the boards used. Smaller boards per linear foot of barrier construction were shown to cause many gaps when shrinkage and swelling occurred (Sterling 1984).

New Product Designs and Opportunities for Wood In Noise Barriers

Using larger, wider planks eliminates some openings and may contribute to a tighter fit of all the planks (Cohn 1981). Sterling recommends better design in the wood noise barriers to eliminate the cracks caused by shrinkage and swelling. For instance, overlapping the boards, using a tongue and groove design, or carefully placing the structural members to control the board movement may remedy the warping problems. Sterling also recommends the use of plywood or laminated wood in the barrier design to minimize the number of gaps. Koppers Industries, Inc. recommends the use of two-inch thick lumber. Koppers also gives a rule of thumb that the width of the lumber should not exceed eight times the thickness to help reduce or minimize warping (Sterling 1984).

Signs and Sign Posts Description

Signs are constructed along roads, highways, and interstates to give directions and inform and warn motorists. Typically, signs are composed of the following pieces: sign blanks, sign faces, and sign posts. The wood products industry is mostly concerned with sign blanks and sign posts. Cunard states in his study on the maintenance and management of street and highway signs that the most widely used sign blank materials are wood (usually plywood) and aluminum. He also states that plastic and reinforced fiberglass have been used for sign blank materials (Cunard 1990).

The first organized roadway signs in the United States have been attributed to the Buffalo Automobile Club, of Buffalo, New York. As early as 1905, the club erected guide signs to give directions to "horseless carriages." The Federal Highway Administration now estimates the total number of traffic signs to be more than 58 million and worth $ 6 billion. This is an average of 15 signs per highway mile. Today, approximately $250 million are spent on street and highway signs annually (Cunard 1990).

Sign and Sign Post Markets

Because of the wide range of supply points for wooden sign posts and plywood used for the sign blanks, no estimate was available for the volumes of these materials used. In Table 6 (page 9), the percentages of different sign post materials used in cities, states, counties, and other government jurisdictions are given. The number of wood sign posts in use is about one-third of steel or aluminum posts. Square wood posts are the dominant wood posts used, with sizes including 4x4s, 4x6s, and 6x6s varying in length from 12 to 18 feet (Cunard 1990).

The rule for choosing sign post material is that it must first meet the American Association of State Highway and Transportation Officials (AASHTO) standards. Second, it must be rigid enough to resist twisting in the wind or collapsing under the weight of snow and ice. Third, the post must be designed to break away or bend over when hit by an automobile. Fourth, signs must be constructed from readily available material that is inexpensive to install and maintain (Cunard 1990).

Table 6. Type of Post Used in Single Post Sign Installations — Percent of Each Material Used,1980.

Material Type and Shape	State	City	County	Other	Total
Steel or Aluminum					
U single	29.8%	48.6%	48.3%	36.6%	34.0%
U back-back	1.2%	0%	0%	0%	0.9%
Square tube	13.6%	10.1%	13.4%	2.9%	12.7%
Round pipe	25.8%	33.3$	5.8%	12.2%	25.6%
Beam	0.2%	0%	0%	NA	0.3%
Angle	NA	1.3%	0%	0%	0.2%
Wood					
Square	28.9%	6.3%	32.5%	38.0%	25.6%
Round	0.5%	0%	0%	4.2%	0.5%
Combination	0%	0%	0%	6.1%	0.1%
Plastic Pipe	0%	0.4%	0%	0%	0.1%

Post Used in Multiple Post Sign Installations — Percent Used by Jurisdiction.

Material Type and Shape	State	City	County	Other	Total
Steel or Aluminum					
U single	32.4%	1.8%	97.8%	4.5%	29.7%
U back-back	3.4%	0%	NA	0%	3.0%
Square tube	7.0%	11.1%	NA	NA	7.2%
Round pipe	5.6%	83.6%	2.2%	0.3%	13.3%
Beam	23.3%	0%	0%	3.8%	20.4%
Angle	0%	0%	0%	0%	0%
Wood					
Square	27.4%	3.5%	0%	53.6%	25.1%
Round	0.9%	0%	0%	15.5%	1.0%
Combination	NA	0%	0%	20.1%	0.3%
Plastic Pipe	0%	0%	0%	0%	0%

Source: "Maintenance Management of Street and Highway Signs," by Richard Cunard. National Cooperative Highway Research Program: Synthesis of Highway Practice 157. September 1990.

Opportunities for Wood Products in Signs and Sign Posts

The ability for the public agencies to maintain the estimated 58 million signs is a monumental task and will largely depend on a systematic approach to maintenance. Private contractors are being used to an increasing degree by states and municipalities. The use of private contractors results from three factors: budget constraints, lack of special skills, and lack of equipment.

Although the trend is rising for the use of contractors, Cunard states that contractors are not used extensively for sign maintenance. Those state agencies using contractors for sign maintenance generally report good results (Cunard 1990).

The need for road sign maintenance is evident. For example, the Pennsylvania Department of Transportation examined 1,626 miles of its roads. There were 37,211 traffic signs on these roads and 60 percent of them needed some form of maintenance. Another example is found in Tennessee. Consultants looked at 3,075 miles of Tennessee roads with 45,200 signs. Maintenance was needed on 36 percent (16,270) of them, 18 percent (8,130) needed to be removed, and 11 percent (4,970) needed to be replaced (Cunard 1990).

Why should road signs be maintained? First, deficiencies in road signs can seriously affect motorist safety and can increase liability exposure for the public agencies. Second, for the forest products industry, the $250 million spent annually could mean large sales revenues. Third, in the 1988 Annual Report on Highway Safety Improvement Programs, improvements to road signs are reported to have the highest benefit-to-cost ratio of any highway safety improvement program (Benefit/Cost of 20.3:1) (Cunard 1990).

Formwork and Falsework Description

Falsework is described as any temporary construction work used to support the permanent structure until it becomes self-supporting. Falsework includes steel or timber beams, girders, columns, piles, foundations, modular shoring frames, post shores, and adjustable horizontal shoring. Formwork is any temporary structure or mold used to contain and support the plastic or fluid concrete in its designed shape until it hardens. Formwork is usually supported by the falsework, which acts as a frame or skeleton bracing system. Formwork is usually composed of plywood sheathing backed with supporting studs, walls, and bracing systems.

Plywood and Plyform

One of the main formwork components is plywood. The first benefit of plywood in concrete formwork is that it can be used many times, with some panels being overlaid 200 times or more. Second, plywood produces a smooth finish on the concrete, and it can be easily bent to form curves. If desired, plywood panels are available in various surface textures for imparting different textures to the concrete. Third, plywood stiffness reduces design deformation during pouring. Finally, plywood insulating qualities help provide consistent curing conditions (American Plywood Association 1993).

The American Plywood Association (APA) has an actual designation for plywood used in formwork called Plyform, which is produced in various grades. Plyform class I is for rough textured concrete finish. High Density Overlay Plyform has an exceptionally hard surface for the smoothest possible concrete finish and the maximum number of uses. Structural I Plyform is stronger and stiffer than Plyform class I, therefore it can be used for higher, heavier concrete structures (APA 1993).

Lumber in Formwork and Falsework

Practically all formwork construction, regardless of the form material used, requires some use of lumber. Softwoods are primarily used for formwork because of their wide distribution and abundance; however, any straight, structurally strong, and sound lumber may be used for formwork. Partially seasoned stock is preferred for formwork, since fully dried lumber swells excessively when it becomes wet. During setting of the concrete and in storage of lumber, green lumber will dry out and warp (Hurd 1981).

There are usually several species of wood that will serve the support job in formwork, and frequently the choice is a question of local availability and cost. Southern pine and Douglas-fir are commonly used in structural concrete forms. Douglas-fir is lighter weight and a little softer than southern pine, while southern pine has moderately large shrinkage, but stays in place well when properly seasoned. California redwood is also used for formwork applications, but has a tendency to stain the concrete. Western hemlock can be used where Douglas-fir and southern pine are unavailable, but western hemlock is generally not as strong. Northern white, sugar, and ponderosa pines are excellent woods for concrete formwork, but are not as abundant as Douglas-fir and southern pine. Therefore, these western pine species are not as economical as Douglas-fir and southern pine (Hurd 1981).

Falsework and Formwork Markets

A large portion of formwork and falsework in transportation is used in building concrete bridges and other roadway structures. There are many types of wood products that are incorporated in formwork and falsework throughout the country. The entire United States highway, railroad, and marine transport system is the market for formwork and falsework (Duntemann et al. 1991).

APA estimates that member mills manufacture approximately 60 million square feet of panels used for concrete formwork annually. The product breakdown by grade is found in Table 7. Cordova (1995) estimates that a large portion of the formwork manufactured will be used in forming bridges, culverts, overpasses, and other transportation structures.

Table 7. Plywood Concrete Formwork Manufactured Annually by APA Member Companies.

Plywood Type/Grade	Million Sq. Ft. Manufactured
B-B Plyform	240
MDO Plyform	75
HDO Plyform	35
Other Grades	250

Source: Bruce Cordova, APA Representative, Houston Texas. 1995.

Competing Products in Formwork and Falsework

Steel panels and beams for formwork and falsework have been very successful. Patented steel panels and dome formwork have been devised for concrete slab formation and steel panels have been used for in-place formwork construction. Most of the steel falsework in use is standard and lightweight structural members, and these steel members are often used in conjunction with wood panels in a concrete form system. The steel falsework serves the same purpose as wood timbers, but allows greater spans or heavier loads than is practically possible with wood timbers. Steel form framing members can last long periods of time with reasonable care and are suitable for reuse (Hurd 1981).

Much like the steel formwork and falsework, aluminum alloys have proven successful in formwork applications. Although aluminum has a higher initial cost, it has a long service life and is very lightweight, thus reducing handling costs. Lighter weight aluminum formwork can be used in construction of concrete units that are impractical with other formwork material; one example is welded

aluminum basement forms. These forms have been made 50 percent wider than framed plywood panels and weigh about the same. Cast aluminum alloy molds are also available to make ornamental concrete products or brick texture on finished concrete walls (Hurd 1981).

Glass-fiber-reinforced plastic is another material competing with wood in formwork applications. This formwork is a combination of materials made up of about one-third glass fiber. Glass-fiber-reinforced plastic is expanding in the formwork market because it is lightweight, is easily molded into shape, and can impart a seamless surface to the concrete. It is capable of producing a high quality concrete finish, can be readily fabricated into complex or nonstandard shapes, and can be readily reused. When greater stiffness is required, wood or metal support members are added, with layers of fiber-glass reinforced plastic coated over them to hold them in place. The main problem with glass-fiber-reinforced plastic is that it cannot be fabricated in the field. Careful temperature and humidity controls must be exercised at all times during the manufacture of the forms. Glass-fiber-plastic formwork also experiences problems with expansion when exposed to hot sun or heat (Hurd 1981).

The last competing materials are fabric forms, bags, mats, and tubes. One example of utilization of fabric tubes is the repair of concrete piles in marine applications. The tubes have a zipper on the side and are supported by steel rings while in use. They are placed around the decaying piling, zipped up, and filled with concrete. Woven mat fabric forms have also been used in water transport systems. The mats are placed on channel and lake banks to cover the entire bank. The mats are then injected with concrete to form a protective sloping bank. These heavy fabric forms have proven successful for underwater construction as well as dry-land formwork construction (Hurd 1981).

THE RAILROAD SYSTEM

Railroad Crosstie Description

Private companies compose the rail freight industry, with tracks ranging in length from one to 23,000 miles. The revenue for these companies ranges from $1000 to over $4.5 billion. The rail freight industry transports 25 percent of the freight tonnage in the United States. There are over 500 railroad freight companies owning 160,000 miles of rail line, employing over 255,000 people, and acquiring combined revenues of over $30 billion (National Transportation Strategic Planning Study 1991). Table 8 classifies the rail freight industry.

Table 8. Profile of the Freight Railroad Industry, 1988.

Type of Railroad	Number and Percentage of Total Companies		Miles Operated and Percentage of Total Miles Operated		Employees and Percentage of Total Employees		Revenues ($ Millions) and Percentage of Total Revenues	
Class I	14	(3%)	140,767	(81%)	231,299	(90%)	27,934	(93%)
Regional	30	(6%)	15,310	(9%)	12,092	(5%)	966	(3%)
Local Linehaul	280	(57%)	14,556	(8%)	6,431	(2%)	666	(2%)
Switching and Terminal	166	(34%)	4,181	(2%)	7,255	(3%)	622	(2%)
Totals	*490*	*(100%)*	*174,814*	*(100%)*	*257,077*	*(100%)*	*30,188*	*(100%)*

Source: National Transportation Strategic Planning Study, Congressional Information Service, 1991

The National Railroad Passenger Corporation, known as Amtrak, controls the majority of the passenger rail service. Amtrak operates 220 trains each day and transports 21.5 million intercity travelers and 10 million commuters annually. Amtrak operates on over 24,000 miles of track in the United States and provides intercity travel to 487 stations nationwide. Amtrak owns only 700 miles of track, operating the rest of its 23,300 miles on freight company trail lines (National Transportation Strategic Planning Study 1991).

Together the rail freight and rail passenger industries have a great need for crossties to maintain and build track. The purpose of the wood crosstie is to hold lines of transverse rail to the correct gage, to bear the load transmitted by the rails, and to transmit and distribute the load with diminishing intensity along the tie length to the ballast beneath (RTA 1986). Today, virtually all hardwoods except the very soft hardwoods, such as cottonwood and willow, are acceptable as tie material. Practically all known conifer species are acceptable crosstie material (Gross 1979). Some exceptions are made for the less dense softwoods, such as spruce.

The first crossties were made of quarried stone. When the Baltimore and Ohio Railroad and the South Carolina Railroad (now part of the Southern Railway system) endured a hard winter in 1832, the quarries supplying the stone ties could not be mined. This was the first time wood crossties came into use. The first wood crossties were hand hewn and untreated, which meant only decay-resistant species, such as white oak, chestnut, cedar, locust, cypress, and the hearts of pine trees, were used. Industrial wood preservation started in the 1870s, with the introduction of the first pressure treated creosote crosstie. These ties were produced by a plant owned by the Louisville and Nashville Railroad at Gautier, Mississippi (RTA 1986).

Crosstie Markets

Today, crosstie production is big business, with millions of dollars invested in crossties each year. Reynolds (1994) states that the current annual crosstie demand is approximately 15 to 18 million crossties per year. The highest demand is for hardwood cross and switch ties, which accounts for 90 percent of production.

The present eastern hardwood region resource is currently adequate in volume and characteristics to support annual production of 18 million per year. This amounts to 600 to 700 million board feet or about 10 to 12 percent of the present United States production of hardwoods in species acceptable for crosstie use (Reynolds 1994). Table 9 gives the approximate installations for crossties over the last 80 years.

Table 9. North American Crosstie Installation History.

Year	Millions of Crossties	Year	Millions of Crossties
1900	100	1961	12
1921	86	1979	25
1936	47	1980	23
1944	51		

Source: Wood Crossties: the Proven Performer, RTA, 1986.

Most wood crossties are produced by small-to medium-sized mills that are cutting from 50 to 200 crossties per day. Some railroads purchase untreated ties and process these ties at their own treating facilities or contract with treating companies for the service. Other railroads purchase treated ties, either on a short- or long-term contract, from a company that produces and treats ties at its own operation (RTA 1986). Table 10 illustrates the volumes of treated crossties produced in the United States in 1993. Table 11 shows the different costs associated with production of different grades of wood crossties.

Table 10. Preservative Treated Tie Production in the United States, 1993.

Preservative Treatment	Crossties 1000 Cubic Feet	Switch and Bridge Ties 1000 Cubic Feet
Creosote Solutions	63,553	6,580
Waterborne Preservatives	33	31
All Chemicals 1993	63,586	6,611
All Chemicals 1991	60,972	6,230

Source: Wood Preservation Statistics, 1993, by James T. Micklewright. American Wood-Preservers Association, 1994.

Table 11. Average Costs for Different Grades of Ties.

Grade	Dollar Cost per Tie
Mainline Ties	$31.11
Branchline Ties	$28.00
Industrial ties	$21.00

Source: Personal Interview with Eric France, July 31, 1995. Western Tar Products Company.

In the future, size and grade requirements may restrict the raw materials available for crossties. For example, the size of trees available relative to required crosstie dimensions may become a supply and cost problem. The changing domestic and international raw material market for low-grade raw materials will have an increasing demand on hardwoods needed for crosstie production. Some wood products that affect the raw material resource are pallets, oak flooring, furniture, and veneer or ply-logs (Gross 1979). Nearly all of class I railroads require 7-inch-thick ties, and the total industry demand for 7-inch ties is approaching 80 percent. Because of the higher quality timber required to produce 7-inch ties and the increasing demand on oak from both the domestic and international markets, limitations will increase on the availability of logs used for 7-inch ties (Reynolds 1994).

Concrete Ties

The steady increase in gross train-car weights has led railroads to consider alternate materials for wood ties. Now, the 125-ton car with 39-ton axle loads is a reality (Buckett et al. 1987). The increased burden supported by rail track will require a more thoroughly engineered track than in place today, and concrete ties may be the future competition.

Early uses of a substantial number of concrete rail ties in North America include the Florida East Coast, Amtrak, and the Canadian National Railroad. More recently, the Burlington Northern railroad installed 150,000 prestressed concrete ties in 1986 (Buckett et al. 1987).

There are three objectives for the use of concrete ties given by Buckett et al. (1987) in the publication "Concrete ties in modern track." First, concrete ties should reduce tie wear by increasing the track modulus and employing better fastener systems to reduce rail movement. Second, concrete ties can be supplied in a kit form with the rail fastener unit already cast in place, eliminating preassembly of the tie. Third, consistent quality of the concrete tie should offer extended service life (Buckett et al. 1987).

Concrete ties need to be in contact with well-compacted ballast to perform adequately. Well-compacted ballast is achieved by replacing concrete ties in a complete line of track, not in a spot replacement method. For this reason, spot replacement of wood ties with concrete ties is not performed. This also leads to difficulties in spot replacement of concrete ties with other concrete ties without lifting the track (Buckett et al. 1987).

Besides the difficulty in replacing wood ties with concrete, the cost of concrete ties is a factor that requires consideration. When using concrete ties, the portion of cost allocated to ties rises 6.4 percent, and the total cost of track installation increases by $6,600. The costs for each track installation can be seen in Table 12 (Buckett et al. 1987).

Table 12. Typical Cost Percentages for Track Materials.

Item	Percent of Cost Concrete Tie Track	Percent of Cost Wood Tie Track
Rail (132 lb. carbon)	42.3%	43.4%
Fasteners	11.2%	16.9%
Ties	32.0%	25.6%
Ballast	14.5%	14.1%
Total $/mile cost	***$247,500***	***$240,900***

Source: "Concrete ties in Modern Track" by J. Buckett, et al. Railway Track and Structures, August 1987.

Steel Ties

Steel rail ties are beginning to take a small share of the crosstie market. Omark Industries produces steel ties with a gage thickness of about 10 millimeters, weighing approximately 185 pounds. These ties range in lengths from 8.5 to 9 feet. The major advantage of steel ties is that specified cants and rail seat configurations can be formed into the tie. Another advantage is the ties downward cavity shape, which serves to confine the ballast and minimize track vibration (Railroad Track and Structures 1987).

Along with the benefits, there are problems with steel ties. First, laboratory tests showed premature tie failure. Without good ballast support, the ties will fatigue early and reduce crosstie service life. Second, steel ties may cause signaling problems unless they have adequate electrical protection between the track and the rail. Omark Industries has noted that its current insulated ties with two-piece, high-density, polyethylene pads have never experienced a signal problem. The life of these pads is only ten years, so this could cause increased track maintenance costs. Omark Industries also admits that the cost of steel ties is more than double that of wood ties (Railroad Track and Structures 1987).

How does Omark Industries justify the use of steel ties? First, the wider spacing of the steel ties results in reduced installation cost per mile. Second, less labor is required for rail change-out and transposition because of direct-fixation rail fastening. Third, Omark expects a more uniform tie life of 50 years to result in extensions of the renewal program (Railroad Track and Structures 1987).

The Wood Crosstie — Holding Back the Competition

Why have wood crossties performed so satisfactorily? First, wood ties have a high strength-to-weight ratio. This is demonstrated when less than 0.5 percent of all wood ties removed from the track are classified as broken. Second, wood is fibrous and resilient, so it is especially effective in withstanding impact loads. Third, wood crossties are highly resistant to fatigue. A crosstie can be loaded to 50 percent of its load carrying capacity for millions of cycles without any measurable loss of strength or permanent damage. Fourth, in contrast to other tie materials, wood crossties rarely experience sudden failure. Fifth, creosote pressure treated ties have a long life, lasting 30 to 40 years. Sixth, wood is a renewable resource, unlike other materials. Finally, wood is the most economically feasible material for crossties (Railroad Tie Association 1986).

New Wood Crosstie Designs: The Super Tie

There are two main types of super ties described in the literature. The first is an engineered wood tie used in high-stress, high-traffic track to prolong track life as long as possible. The heartwood is placed on the up side of the track for highest density, and the wear plate is attached with heavy screws. These heavy screws are engineered to fit tightly into the wood tie and prevent movement at the interface between the tie and the plate. The attachment of the tie plate is performed at the crosstie factory. The super tie is then installed into the track with conventional spikes to allow the track to bend or flex as the train passes. The Canadian Pacific Railroad installed 3,000 super ties in curves of eight degrees where tie cutting was most noticeable. After one year in service and more than 70 million gross tons of traffic, no wear was apparent on the surface of these ties (Kramer 1993).

A second kind of super tie is made from dowel-laminated oak and mixed hardwood pieces. The argument for these wood ties is that the components procured from smaller diameter logs are sounder, stronger, and will dry and treat better than larger logs (Reynolds 1994). The dowel-laminated wood ties perform well in heavy duty, mainline service track, and have a prospective service life of 30 to 35 years (McIntosh 1994). These ties will also allow maximum utilization of smaller logs that generally is not identified with wood tie production (Kramer 1993).

The Recycled Wood Tie

One innovative company, Reconstituted Crosstie Technologies, Inc., is resurrecting the cedrite tie project. The cedrite tie is made from small chips procured from used wood ties and a special resin that completely penetrates the wood under high pressure and temperature. The crossties are then formed in a press much like Oriented Strand Board (OSB) or particle board. The cedrite tie is rot, water, insect, and fire resistant. Reconstituted Crosstie Technologies, Inc. is presently testing cedrite ties and plans to build a plant in Kansas City, Kansas (McIntosh 1994).

THE MARINE AND INLAND WATERWAY SYSTEM

Marine Wood Description

Marine applications of wood, especially pilings, represent a large market for wood products. The wood used in marine applications can be lumber, timbers, plywood, and piling. The primary wood uses are for piers, wharves, retaining walls, docks, water-breaks, and formwork and falsework used to build concrete marine structures.

Marine Wood Markets

The United States has the world's largest port system with roughly 2,500 ports, subports, and other facilities. The first market for the wood products industry is in building more spacious marine and inland waterway terminal facilities for cargo handling, storage, and transportation system interfaces (moving cargo from ship to truck or ship to rail). The building of these structures will mean increased use of wood pilings, lumber, and wood structure panels in structures as well as the use of formwork and falsework for concrete construction (National Transportation Strategic Planning Study 1991). The second market for the wood products industry relates to the age and size of locks in relation to growth of inland waterway traffic. As the inland waterway traffic grows, the need for expanding the lock system will increase, requiring more falsework to build concrete locks and dams (National Transportation Strategic Planning Study 1991).

The third market for wood products in water transport is building, repair, and maintenance of recreational docks, piers, and wharves. The annual economic loss of marine structures to wood destroying organisms exceeds 500 million dollars in the United States, not including damage to structures along inland waterways (Helsing 1984). Above the water line, fungi and insects do the most damage to wood structures. Below the water line, wood boring fauna are the primary wood destroying agents (Oregon State University Extension Service 1981). Also, bacteria have been found to attack marine wood structures underwater in an anaerobic condition. Strength losses of 30 percent and higher have been reported for softwood piles following bacterial attack during storage (Eslyn and Clarke 1975). As long as organisms are able to attack marine structures (concrete, steel, and wood alike), there will be a market for more wood products.

More than 40 percent of the United States marine terminals are located in 15 port cities with 500,000 or more people. The U.S. Army Corps of Engineers is constantly building and improving United States harbors. These expenditures represent a large market for wood products, including formwork, falsework, piling, lumber, and structural panels. Table 13 shows the total amount spent between 1985 to 1990 on harbor improvement construction.

Table 13. U.S. Army Corps of Engineers Harbor Improvement Expenditures.

Year	Construction ($ millions)	Operations and Maintenance ($ millions)
1985	83.0	382.0
1986	66.0	333.0
1987	80.0	320.0
1988	114.0	317.0
1989	115.0	361.0
1990	128.0	343.0

National Transportation Strategic Planning Study. Congressional Information Service, 1991.

The major funding for publicly owned facilities varies by source and type of facility. The main source of funds for capital investment include commercial market instruments, direct subsidies, public-private ventures, and other means, such as user charges and state lotteries. Privately owned terminal facilities generally are operated by the owner or are leased to a private operator (National Transportation Strategic Planning Study 1991).

Table 14 reports the amount of wood pilings treated in 1993.

Table 14: Treated Pilings Produced in the United States.

Preservative Treatment	Piling Volume Produced (1,000 cubic feet)
Creosote Solutions	2,944
Oilborne Preservatives	12
Waterborne Preservatives	5,775
All Chemicals 1993	8,731
All Chemicals 1991	6,770

Souce: Wood Preservation Statistics, 1993, by James T. Mickelwright. American Wood-Preservers Association, 1994.

Performance of Marine Wood Pilings

The main species used for marine wood pilings are southern pine and Douglas-fir. Southern pine is widely used in marine applications because it is possible to saw the wood with treatable sapwood on all sides. The heartwood of softwood species will not absorb treatment chemicals well enough to protect the wood. Other pine species have been used in both salt and fresh water applications. Eslyn and Clarke (1975) performed a study of red pine, white pine, and tamarack pilings submerged in river water for 85 years and found that although the strength value for the piles had been considerably altered compared to new poles of the species, the piles had performed successfully.

The United States Navy performed a joint project with the Marine Piling Committee of the USDA Forest Service, Forest Products Laboratory, to test the performance of Douglas-fir and southern pine piles. The main part of the test where comparisons could be made were the piles placed at Wrightsville Beach, Los Angeles, California. These piles had been submerged for twenty years. Table 15 shows the comparison data for this joint study. The Douglas-fir poles seemed to perform best with the dual creosote-CCA treatment, while the southern pine poles performed best with the creosote/coal tar solution.

Table 15. Results of Marine Piling Joint Navy Inspection of Marine Pilings.

Treatment	Pile Species	Wrightsville Beach Location. Percent of Pile Cross Section Remaining
Dual treated		
CCA and Creosote	Douglas-fir	99%
	Southern pine	77%
ACA and Creosote	Douglas-fir	100%
Standard Creosote		
Creosote/Coal tar Solution	Douglas-fir	43%
	Southern pine	93%

Source: "Cooperative Marine Piling Project. Joint Navy-Industry Inspection of Marine Piles - Report III," by J.D. Bultman, and D.A. Webb. AWPA Proceedings, 1985.

Chaffing Problem for Marine Wood Applications

A common problem with wood is damage to the preservative shell of pilings that occurs when metal brackets, floating docks, or floating debris rub against wood piles. This chaffing action gradually wears away the treated shell and exposes untreated interior wood, causing the piles to decay. Surveys of several Oregon ports, by Morrell in his study on marine wood chaffing, indicate that 10 to 25 percent of piles exhibited chaffing damage. This damage can range from minor to severe. Severe damage results when large portions of the piling are ground away. If this chaffing action causes a five-to-ten year loss to a $500 to $1,000 Douglas-fir pile, the loss to service life can be economically significant. Newbill and Morell (1985) make several suggestions for preventing wood chaffing, including using rubber rollers between floating docks and piles, using metal rollers to attach the docks to the piles, and using rounded wooden and metal collars to encircle the pile supporting the docks.

ELECTRICITY AND COMMUNICATIONS TRANSPORT SYSTEMS

Wood Utility Poles Description

In the United States there are 2,022 state and local publicly owned electric utilities, 254 investor-owned, 10 federally owned, and 941 cooperative borrower electric utilities. These are the primary consumers of wood utility poles. Wood utility poles are structures used to support the electric and telecommunications transportation lines. The poles range in length from 30- to over 100-feet in length and from 10 to over 20 inches in diameter. The first poles implemented for utility purposes were in 1844 and were made of untreated chestnut. Since that time, more than 250 million wood poles have been used (Fox et al. 1987).

In 1897, the first pressure treated creosote poles were implemented in the Washington and Norfolk line, which was built by American Telephone and Telegraph. This telephone line consisted of 9,975 creosote-treated southern pine poles. Some poles near Bowling Green, Virginia, are still in use after more than ninety years. Since the chestnut blight of the 1920s and 1930s, utility poles began to be made of other preservative treatable species. Today, nearly all the poles used by utilities are produced with treated wood (Taylor 1988).

One of the most sociologically beneficial programs of the twentieth century was the Rural Electrification Act signed by President Franklin Roosevelt. The Act greatly impacted the wood poles industry by initiating the construction of over half the miles of distribution lines in the United States. These lines now serve over 70 percent of the United States land area (Taylor 1988).

As of 1991, over 11 million miles of overhead distribution lines and 1.5 million miles of overhead transmission lines were in service. It is assumed that 95 percent of these lines are supported by wood utility poles, with an average distance of 350 and 400 feet between poles. This equates to between 138 to 158 million poles currently in service. It has been estimated that 1 to 2 million new poles are used each year, each costing $200 to $400 with installation costs two to three times this amount: pole installation costs can be as high as $2,000. On average, utilities are spending $500 to $600 million a year on wood (Ng 1994).

Table 16 has data on the production of treated poles in the United States in 1993.

Table 16. Estimated Treated Poles Production in the United States, 1993.

Chemical Treatment	1,000 Cubic Feet Volume
Creosote Solutions	10,957
Oilborne Solution	32,757
Waterborne Solution	19,984
All Chemicals 1991	63,698
All Chemicals 1993	71,734

Source: Wood Preservation Statistics, 1993, by James T. Micklewright. American Wood-Preservers Association, 1994.

Wood Pole Supply

Over 70 percent of the annual production of wood poles in the United States has traditionally come from southern pine forests. The southern pine pole market may soon have some difficulties attaining a consistent supply. The shift in the forest industry emphasis from the West to the South has led to a drain on the supply of mature southern pine timber. At the present time, the southern pine forest is producing about 60 percent pulpwood and 40 percent sawtimber. About 15 percent of the sawtimber, or about 6 percent of the total southern pine forest, is suitable for pole production. Competitive supply pressure has increased and will push pine timber prices higher. Southern pine prices are projected to rise faster than the inflation rate.

As natural stands of pole-quality timber are harvested, poles are generally not being regrown on a planned cycle. Management practices have caused the percentage of pole quality southern pine to drop steadily over the years. An important factor in the southern pine pole supply is the trend of utilities' demands for longer and larger poles (Wright 1979).

Another management problem with growing southern pine poles is the rotation time necessary to produce the pole-sized timber. The trees large enough to produce poles for utility purposes require 35 to 40 years for growth on scientifically managed land, while plantation pine is usually grown only on a 25- to 30-year rotation. The longer growing time needed to grow southern pine poles and the potential loss of wood volume by growing poles for this longer time means a lower return on investment. The need and the equal market for smaller trees, along with the shorter investment time makes the shorter rotation economically efficient, so fewer pole length pines are produced (Wright 1979).

The southern pine pole-quality timber is the most highly valued part of any forest crop and is equally suitable for utilization in wood product uses that are more economical. Greater concentrations of wood product plants in the South and increasing use of southern pine for sawtimber and plywood are causing some extension in rotations on forest industry lands; however, poles will not be grown unless they can compete in price with other forest products. Unless poles will justify the investment in the southern pine forest, the investment will not be put into pole production (Wright 1979).

Pole Suppliers

About half of all raw material for pole production comes from independent operators. The remaining raw material comes from contract crews or company crews. "White" or debarked poles are procured for treating plants from distances up to 300 miles from the plant, and barky poles are produced from a radius of 100 miles. Plants as far inland as Arkansas have hauled poles from areas along the United States east coast (Williston and Screpetis 1975).

Concrete versus Wood in Pole Production

When choosing a utility pole material, Taylor (1988) recommends four determining factors in his study of concrete versus wood poles. First, the material must be plentiful and uniform. Second, the family of poles should be designed for the loads that are planned for the system. Third, the utility poles should be built from material that will endure longer than the life of the utility line. Finally, quality control of the pole material should be carefully monitored during the pole manufacturing process (Taylor 1988).

The first concrete pole activity was documented in an October 1924 report titled, "The Design and Manufacture of Concrete Poles" published by the committee on Power Distribution of the American Electric Railway Association. There are four basic types of concrete poles on the market. The first is cast concrete, which is a cast pole using reinforcing rods for strength. The second is prestressed cast concrete, which is similar to cast poles except the reinforcing wires are under tension when the pole is cast. The third is spun concrete, which is a pole having a reinforcing rod cage that is placed in the mold, and the mold is then rotated (like a centrifuge) for uniform distribution of the concrete. The fourth is prestressed spun concrete pole, which is similar to a spun concrete pole except the wires are under tension (prestressed) while the mold is being spun (Taylor 1988).

Concrete Pole Versus Wood — Advantages and Disadvantages

Taylor reports that the largest problem with concrete poles is finding foundations that will support the pole and not allow it to bend or flex. The strongest benefit of the concrete pole is in its appearance, unless it darkens because of molding. The expected lifespan of concrete poles is 10- to 20-years shorter than that of wood poles for a number of reasons. The shortened service life is caused by the flexing of concrete poles while the pole is being transported. Concrete's inherent strength is in compression loading. In a tension or cantilever situation, the strength capability of concrete is low, especially for concrete poles. An additional problem occurs when a concrete pole is flexed or stressed under tension. This condition can lead to hairline cracks that will allow moisture to enter the pole. These cracks cause steel reinforcements to corrode, weakening them. Therefore, concrete poles can deteriorate more rapidly than wood poles if handled improperly. The integrity of the concrete pole is only as good as the steel reinforcing (Taylor 1988).

Trees are suited for both compression and cantilever loading; the crown produces compression loading from its weight and cantilever loading from the wind forces exerted on it. Therefore, wood performs well in the loading situations that poles encounter. Wood also has an inherent shock-loading capacity; it can withstand a great deal of shock due to its natural resiliency. Concrete poles do not withstand shock loading like wood poles and will crack or fail if subjected to shock loads. During the San Fernando earthquake of February 9, 1971, frequent failure of concrete structures, especially poles, were seen due to concrete's inability to withstand shock. The Bureau of Standard's study on the earthquake reported no failures of utility lines due to failure of wood utility poles. Concrete poles require more production time than wood poles. For example, concrete poles need 28 days to cure after removal from the mold, which would require a large storage holding of concrete poles for emergency situations (Taylor 1988).

Soil conditions can also cause situations where concrete poles fail, but wood poles do not. Taylor noted that a 1967 study showed concrete poles set in alkaline soil conditions will fail in as few as 18 months (Taylor 1988).

Finally, the weight of concrete poles makes them more expensive than wood poles. A 50-foot concrete pole is double the weight of a 50-foot wood pole. This necessitates special handling equipment and methods, and greatly increases shipping and handling costs. Unloading equipment on trucks or in yards would have to be examined for adequate capabilities. Existing construction equipment and practices may not be sufficient to safely handle the increased weight of the concrete pole (Taylor 1988).

Another disadvantage of concrete poles not found in wood poles is the workability of the pole in the field. When concrete poles are cast, it is important that all holes for attachments of hardware be in place at the molding process. Drilling holes in concrete poles in the field means a high risk of cutting a reinforcing rod and weakening the integrity of the pole (Taylor 1988).

All these factors play a large part in the increased cost of concrete poles. In Table 17, a cost comparison is presented for concrete poles versus wood poles and steel lattice poles. The dollar values may have changed since Taylor's study in 1988, but they clearly show wood and laminated wood poles were more economical than concrete or steel.

Table 17. Concrete, Wood, and Steel Pole Cost Comparisons.

Pole Type	Cost per Mile
Concrete	$13,200
Natural Wood	$8,500
Laminated Wood	$12,800
Steel Lattice	$26,000

Source: "Comparison Between Wood Poles and Concrete Poles for use in Electrical Distribution Systems," by James A. Taylor. American Wood-Preservers Association Proceedings, 1988.

New Wood Pole Designs and Opportunities

Laminated wood has been used in the United States since 1934 and was used in Germany and other European countries long before that. The oldest utility application of laminated veneer poles is 90 foot, 115 kV columns installed in the early 1960s near Birmingham, Alabama, for the Alabama Power Company. Laminated veneer poles are produced from veneer lumber glued together under tension with an octagonal cross-section (McKain 1975).

There are several advantages of the laminated veneer pole. First, the strength-to-weight ratio is very high. Engineered timber is stronger pound for pound than any other structural material (McKain 1975). Second, Walser et al. (1988) states in a study of laminated wood poles that the strength properties of laminated veneer poles can be closely controlled, thus alleviating problems with hidden weaknesses in solid wood poles. Third, laminated poles are much lighter than solid wood poles (they are usually hollow), reducing the transport costs. Walser et al. (1988) reports that a hollow, 40-foot laminated wood pole weighs 513 pounds, which is half the weight of a comparable solid wood pole. This light weight makes laminated wood poles very easy to erect. Fourth, laminated veneer poles are low maintenance and when properly treated can last as long or longer than solid wood poles. Fifth, laminated veneer is a good insulator from electricity. Finally, laminated veneer poles can be cost competitive with solid wood poles since lower quality wood can be used to make the veneers (McKain 1975).

Another engineered wood utility pole similar to the laminated veneer pole is the composite wood pole. This pole is made from flaked wood panels like that of oriented strand board (OSB) with the panels

glued together in an octagonal shape like the laminated veneer pole. The composite wood pole, or Compole, has a strength-to-weight ratio, uniform properties, and relatively low cost. Compoles have the advantage of being less flammable and no more corrosive than treated solid wood poles, which makes them ideal for manufacturing. There are possibilities for production, but they have not been commercially produced to date. Based on structural design data, Adams et. Al. (1981) concluded that Compoles could be used for utility poles as well as transmission tower construction.

OTHER WOOD PRODUCTS IN TRANSPORTATION

Salt storage buildings, a wood product addressed in this study, are another means of using wood products in transportation. The second largest end use for salt in the United States is for highway deicing. In 1990, over 11.3 million short tons of salt were used in highway deicing (Kostick 1992). A significant problem with this large amount of salt is how to properly store it, especially with present and future EPA guidelines concerning industrial water runoff and water quality. A problem with using concrete and steel to build salt storage buildings is that the salt will corrode the structure. Salt on roads has been associated with corrosion of motor vehicles, bridge decks, unprotected steel structures, and reinforcement bar and wire used in road construction (Kostick 1992). A viable solution to the salt corrosion problem is to construct the salt storage buildings from wood materials. Wheeler Consolidated, Inc. claims that wooden salt storage buildings will not pit or rust and are not affected by temperature, alkali soils, or acids. Promotional literature distributed by Advanced Storage Technology, Inc. (1988) of Elmira, New York, claims the following benefits with wood-constructed salt storage buildings:

- protect against environmental problems,
- provide a safer working environment,
- are aesthetically pleasing structures and can be painted any color,
- require little maintenance, and
- are constructed of non-corrodible wood.

Other transportation structures of concern to the wood products industry are small bridges used in off-road transportation, specifically pedestrian foot bridges and small vehicle bridges. Promotional literature distributed by Wheeler Consolidated, Inc. (1988) makes the following claims about small timber bridges:

- are constructed faster in any weather,
- are more easily maintained than bridges made from other material,
- are visually pleasing, and
- are durable (especially if made from pressure treated wood).

A few possible markets for these smaller bridges are public parks and recreation areas with trails and small roads, golf courses, and private developments such as farms, estates, or communities.

PRESERVATIVE TREATED WOOD IN TRANSPORTATION MARKETS

In the transportation industry, extension of wood products service life is important for two reasons: wood products are used in support and construction of the transportation infrastructure, and they are often expensive to replace. Extension of wood products service life is accomplished through two primary operations. The first is chemical preservative treatments before implementation of the wood products. The second is remedial chemical treatments after the wood products are in service.

The railroad is a main consumer of treated wood because crossties supporting the track must remain solid for many years. The most prevalent chemical preservative treatments for wood crossties are creosote solutions and waterborne solutions, such as Copper Chromated Arsenate (CCA), Ammonium Copper Zinc Arsenate (ACZA), and Copper Zinc Chromate (CZC) (RTA 1986). The amount of treated wood ties represents a huge percentage of the total volume of wood treated per year. Creosote-treated crossties are 69 percent and switch/bridge ties are 7 percent of the total 82.5 cubic feet of creosote-treated wood in 1993 (Micklewright 1994).

Utility companies invest large capital expenditures on wood poles, another treated wood product, each year. Because of these expenditures, companies want the poles to last. In the past, as utilities began using less durable species, such as chestnut and cedar, the use of treated wood grew and nearly eliminated the use of untreated wood. Creosote was the first preservative widely used for the treatment of wood poles, railroad crossties, and other wood products subject to decay. Creosote also has performed well as a preservative (Nicholas 1994). The Washington to Norfolk utility line built by AT&T in 1897, used nearly 10,000 creosote utility poles. After 17 years in service, 98 percent of the poles were still in service, and 89 percent had no decay. In 1927, after 30 years of service, an inspection showed that a large number (the number was not specified) were still in service. In 1979, 38 of the original creosote treated poles were still in service after 83 years (Webb et al. 1981).

Wood poles are produced using a variety of other preservative solutions, including: oilborne solutions such as pentachlorophenol, copper naphthenate, zinc naphthenate, copper-8 quinolinolate, and TBTQ (97 percent pentachlorophenol); and waterborne solutions, such as CCA, ACZA, and CZC (98 percent CCA). Production of treated wood poles has been fairly steady, with perhaps a slight downward trend since the middle 1980s. Table 18 shows that treated poles are a large portion of total treated wood produced in 1993.

Table 18. Wood Poles as a Percentage of Total Wood Treated in the United States (1993).

Preservative Treatment	Wood Poles Percentage of Total Wood Treated	Total Wood Volume Treated 1,000 Cubic Feet
Creosote	11.89%	82,488
Oilborne	89.96%	33,721
Waterborne	4.25%	398,070

Source: Wood Preservation Statistics, 1993, by James T. Micklewright. American Wood-Preservers Association, 1994.

Joe Morgan, III (1992) performed a comparison of Douglas-fir and western red cedar poles that demonstrated that the relatively new ACA treatment performs well in service. The average age of the two western species appears to demonstrate ACA and creosote treated poles having comparable life cycles, with Penta treated poles somewhat behind in service life (Table 19).

Table 19. Average Replacement Age of Two Western Species Poles and Their Treatments(1992).

Treatment	Douglas-fir Replacement Age (Years)	Western Red Cedar Replacement Age (Years)
ACA	34.41	----
Creosote	29.9	35.3
Pentachlorophenol	18.6	29.5

Source: "Longevity of Treated Wood Utility Poles in the Pacific Northwest," by Joe Morgan III. American Wood-Preservers Association Proceedings, 1992.

The replacement percentage for Douglas-fir with ACA treatments has the greatest longevity, with Penta next, and then creosote treated poles (Table 20). It appears that creosote poles may have the longest service life in some instances as demonstrated by the average age of the creosote-treated western red cedar (Table 19). In fact, creosote treated poles also have the highest replacement percentage, as seen in the western red cedar (Table 20).

Table 20. Replacement for Two Species and Their Treatment (1992).

Treatment	Douglas-fir	Western Red Cedar
ACA	4.5%	----
Creosote	18.4%	29.6%
Pentachlorophenol	7.1%	14.5%

Source: "Longevity of Treated Wood Utility Poles in the Pacific Northwest," by Joe Morgan III. American Wood-Preservers Association Proceedings, 1992.

Other new wood pole preservatives are being tested and are gradually becoming a major force in the industry. Ammoniacal copper quinolinolate (ACQ) and chlorothalonil were both recently approved by the American Wood-Preservers Association (AWPA) technical committee and may be used on poles. Future wood preservatives will have lower mammalian toxicity, be more environmentally compatible, and provide long-term protection (Nicholas 1994).

Much like wood poles and rail ties, the main treatments for marine wood products and pilings are creosote solutions, CCA, and ACA. However, single treatments of either creosote, CCA, or ACA are often not sufficient to protect wood in marine use. Creosote will protect piles against molluscan borers, teredinids, and phloads but not against *Limnoria spp.* CCA and ACA will protect against *Limnoria spp.* but not against molluscan borers. The AWPA recommends using a dual treatment of CCA or ACA and Creosote (Webb et al. 1987). The drawback to this is the expense entailed in the dual treatment of the wood piles. Pendleton (1988) performed a study on 27 piles with experimental preservative treatments in Pearl Harbor, Hawaii, in 1988. Pendleton found that basic zinc sulfate is the most successful single waterborne salt treatment. Another single preservative treatment that performs well is copper oxinate in xylene. Both of these treatments are considered low environmental hazards (Pendleton 1988).

Remedial Treatments

Once the wood products are in place, the initial preservative treatments may not be sufficient to protect the products from decay for the desired service life. The wood products may be used in unusual circumstances that could cause early failure, and a remedial chemical treatment may be necessary to extend the product's service life. Several transportation sectors are using remedial wood treatments, including railroads, electric and telecommunications utilities, and the marine transportation industries.

German Federal Railways have remedially treated wood crossties using diffusible fumigant rods containing sodium fluoride since 1965. This cartridge system was marketed in the United States under the name Tie-Guard. Since 1986, nearly 20 million ties have been remedially treated in the tie plate area to prevent decay and increase service life (Ostby 1992). Another remedial treatment designed to extend tie life is to place preservative pads, which combat decay, in the tie plate area. Since 1988, railroads have placed more than 13 million of these biodegradable pads in the track system (Ostby 1992). Rail crossties are remedially treated by pouring fumigant preservatives into open spike holes.

On average, 1,200 to 1,800 ties per mile are treated in this manner. The benefits of this method are that remedial treatments can be done on active track and the treatment is site specific with the preservative restricted to the tie plate area (Ostby 1992).

Similar to the railroads, utility companies often face early wood pole decay despite chemical preservative treatments. The dominant cause of decay is pre-treatment infection that occurs when untreated poles are stored or air-dried for too long (Taylor 1980).

In his study on remedial treatments for in-service utility poles, Butera (1994) states that southern pine poles are most susceptible to "shell rot" or surface decay below the ground level. Decay that starts during the service life of wood poles occurs most frequently in the area one to two feet below the ground line (Ng 1994). Replacement of wood utility poles because of decay, whether starting before or after treatment, is an ongoing and costly process. Research has led to four types of remedial chemical treatments for wood poles commercially available today. These are brush-on preservative pastes and bandages, liquid internal treatments, fumigants, and diffusible rods (Butera 1994).

The marine transportation industry has a large need for remedial treatments of wood structures. Above the water line, wood planks and boards are replaced as they decay, leading to increased maintenance and liability costs. Several protective methods have been suggested for above-water remedial treatments of marine wood.

1. Application of pentachlorophenol, copper 8 quinolinolate, fluor chrome arsenic phenol, and ammonium bifluoride or boron.
2. Apply treated roofing felts between the wood members.
3. Kerfing can be implemented to control checking which traps decay organisms. (Morrell et al. 1987).

Kerfing is making a saw cut in the end of wood timbers and piles, which will relieve stress caused as the wood shrinks and swells. Unlike with poles and rail ties, fumigants used in the marine environment appear to only provide a temporary barrier against fungus, and fumigants will not stop the advancing fungi when the organisms are present in the wood (Newbill and Morrell 1991).

CONCLUSION

The four transportation industries in the United States offer great opportunities for the wood products industry. The annual highway expenditures for construction and maintenance amount to $60 billion. The main suppliers of these funds are state governments and the federal government (totaling over 97 percent of funds collected). The key decision makers pertaining to materials used in highway construction and maintenance are state highway engineers and officials, locally elected and appointed highway officials, and private highway contractors. The yearly volume of wood, except for timber piling, is expected to average over 7,400 board feet per million dollars of construction cost (this figure was derived from the average timber used over the years 1990 to 1992). The $60 billion per year spent on highways equates to over 444 MMbf of wood used in highway construction (Highway Statistics 1992, 1993).

Railroad expenditures on construction and maintenance of track amount to $7.46 billion annually. Because the majority of the railroad system is operated by the private sector, little is known about the current condition of the tracks. The current annual crosstie demand is approximately 15 to 18 million crossties per year, but this may change in the future. This averages to 660 million board feet of wood used in crossties annually. Ninety percent of these ties are hardwood, and the green value of crossties used per year is over $255 million.

The wooden marine structure losses in the United States exceeds $500 million annually. These structures can be replaced with wood that will last longer if treatments and construction are performed correctly. The U.S. Army Corps of Engineers alone spends over $300 million per year on harbor improvements. The U.S. Army Corps of Engineers, the U.S. Navy, and people from both the public and private sectors who own and operate marine installations are responsible for the building and reconstruction of marine structures.

The electricity and telecommunications industries spend over $500 million annually on wood products, specifically wood poles. The 3,227 electric companies in the United States invest in over 2 million new poles annually. Currently, these companies maintain over 12.5 million miles of distribution and transmission lines in the United States.

Bruce Cordova (1995) of the American Plywood Association estimates total construction spending in the United States to exceed $450 billion this year, with $125 billion expected to be spent on the transportation sector. In summary, the annual estimates for the potential markets for wood products in transportation were:

- $500 million replacement value for wood in marine use,
- $600 million in wood poles,
- $255 million in crosstie utilization and replacement,
- $178.3 million in guardrail upgrades,
- $3.4 million in sound barriers, and
- $250 millionin highway signs.

The total amounts to over $1.7 billion that could be spent on wood products. This total does not include the amount spent on formwork and falsework because an estimate for their use in transportation could not be found. The volumes of wood and the amount spent could not be found for salt storage buildings and small vehicle and foot bridges, but they represent possible markets for wood products in transportation.

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August 1997